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TESTING AND ANALYSIS OF A THRUST STAND SYSTEM

A. J. COUVILLION AND N. G. TINLING

TECHNICAL REPORT NO. AFRPL-TR-66-343

DECEMBER 1966

AIR FORCE FLIGHT TEST CENTER
AIR FORCE ROCKET PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
EDWARDS AIR FORCE BASE, CALIFORNIA

PREPARED BY
HUGHES RESEARCH LABORATORIES
MALIBU, CALIFORNIA
CONTRACT NO. AF 04 (611) -11379

TESTING AND ANALYSIS OF A THRUST STAND SYSTEM

A. J. Couvillion and N. G. Tinling

FOREWORD

This is the Final Report on Contract AF 04(611)-11379. The contract was initiated under Project No. 3850, "Design, Development, and Fabrication, Delivery, and Installation of a High Response, Low Level, Pulse Engine Thrust Stand System," Task No. 673850, "Thrust Stand." The work was administered under the direction of the Air Force Flight Test Center, Rocket Propulsion Laboratory, W. L. Buccholz, project engineer.

This report covers work conducted from November 1965 to October 1966.

This technical report has been reviewed and is approved.

Wallace L. Buchholz
AFRPL (RPFTR),
Project Engineer

ABSTRACT

This report presents the results of a dynamic evaluation of a Thrust Stand System designed under Contract AF 04(611)-10536. The testing includes sinusoidal power measurements from 10 cps to 2000 cps using an electrodynamic shaker as the input force and step unload force input with a decay time of less than 0.1 msec. The results are presented in terms of acceleration, displacement, and force as appropriate to the components under test.

FOREWORD

This is the Final Report on Contract AF 04(611)-11379. The contract was initiated under Project No. 3850, "Design, Development, and Fabrication, Delivery, and Installation of a High Response, Low Level, Pulse Engine Thrust Stand System," Task No. 673850, "Thrust Stand." The work was administered under the direction of the Air Force Flight Test Center, Rocket Propulsion Laboratory, W. L. Buccholz, project engineer.

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Project Engineer

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SECTION I

INTRODUCTION

This report presents the results of vibration and force measurements which were made at the Environmental Laboratories of Hughes Aircraft Company on a High Response, Low Level Thrust Stand System. The equipment was designed and fabricated by Hughes Research Laboratories under Contract No. AF 04(611)-10536. The objectives of this effort were to analyze the thrust stand system using government furnished engines; to determine all resonant frequencies and their origin; to eliminate resonances caused by engine brackets, mounting techniques, and propellant lines; and to make recommendations for minimizing engine and propellant valve resonances. The scope of this effort also included design, fabrication, test, and delivery of engine mounting brackets, propellant lines, and bellows.

SECTION II

COMPONENT DESIGN

The detailed design of hardware such as engine mounting brackets, propellant lines, and bellows is essential to the performance of the thrust stand system. In the design of the brackets for the Marquardt and Rocketdyne engines, consideration has been given to stiffness and weight as they affect the stand and mounting provisions which affect the operation of the engines. The designs presented have been tested and found to be adequate. In the design of the propellant line bellows, previous experience has led to a unique but simple component which performs well. Satisfactory performance of the engine mounting platform suspension in conjunction with the propellant bellows is essential to system performance; the design of this system is quite satisfactory.

The location of these components on the complete thrust platform is shown in Figure 1. The Engine Mounting Adapter shown in the figure was designed for the Marquardt engine. A dummy engine is installed in the adapter shown in the figure. The propellant line bellows are shown capped at the point where the rigid line attaches between the engine and the bellows.

A. PROPELLANT LINES AND BELLOWS

Propellant lines from stationary points on the thrust stand to the propellant valves have been installed. The propellant lines are fabricated of 304 stainless steel tubing and are compatible with the port size on the propellant valves. Specially designed bellows sections have been installed between the stationary thrust stand base and the engine mounting platform. Two bellows sets were fabricated by Metal Bellows Corporation, Chatsworth, California, in accordance with the specifications shown in Figure 2. The combined spring rate of the propellant line bellows and the flexures of the platform suspension system is 500 lb/in. This spring rate is less than 0.1 % of the system spring rate. This stiffness is dictated by the contractual requirement that the bellows lines be designed so that when a 100 lb force is applied to the thrust stand system, no more than 0.1 lb will be absorbed by the propellant lines. The bellows lines were designed to minimize the bourdon tube effect of pressurized lines. A 500 lb change in pressure results in an apparent thrust change of no more than ± 0.1 lb.

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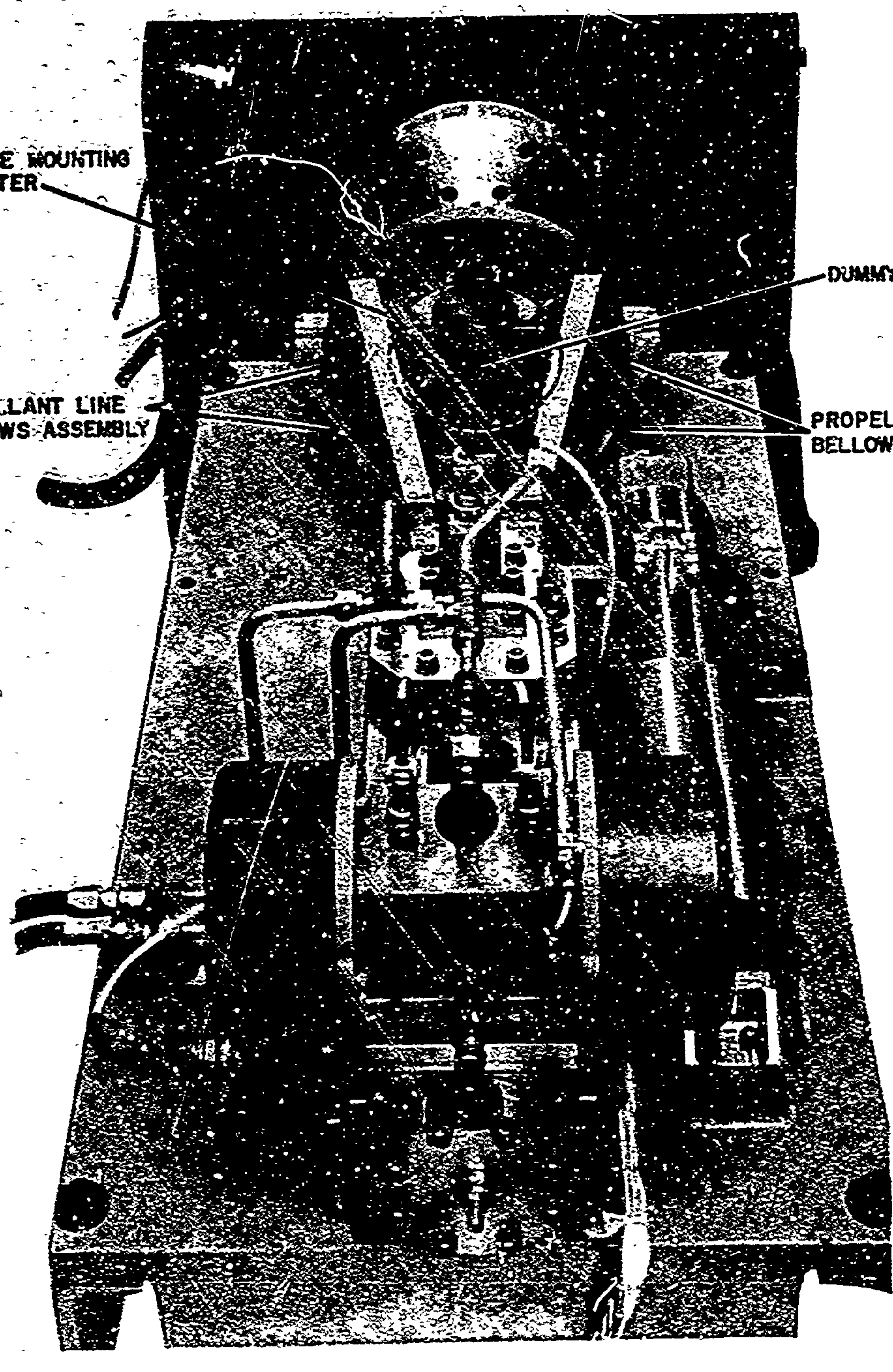


Figure 1. Complete thrust platform.

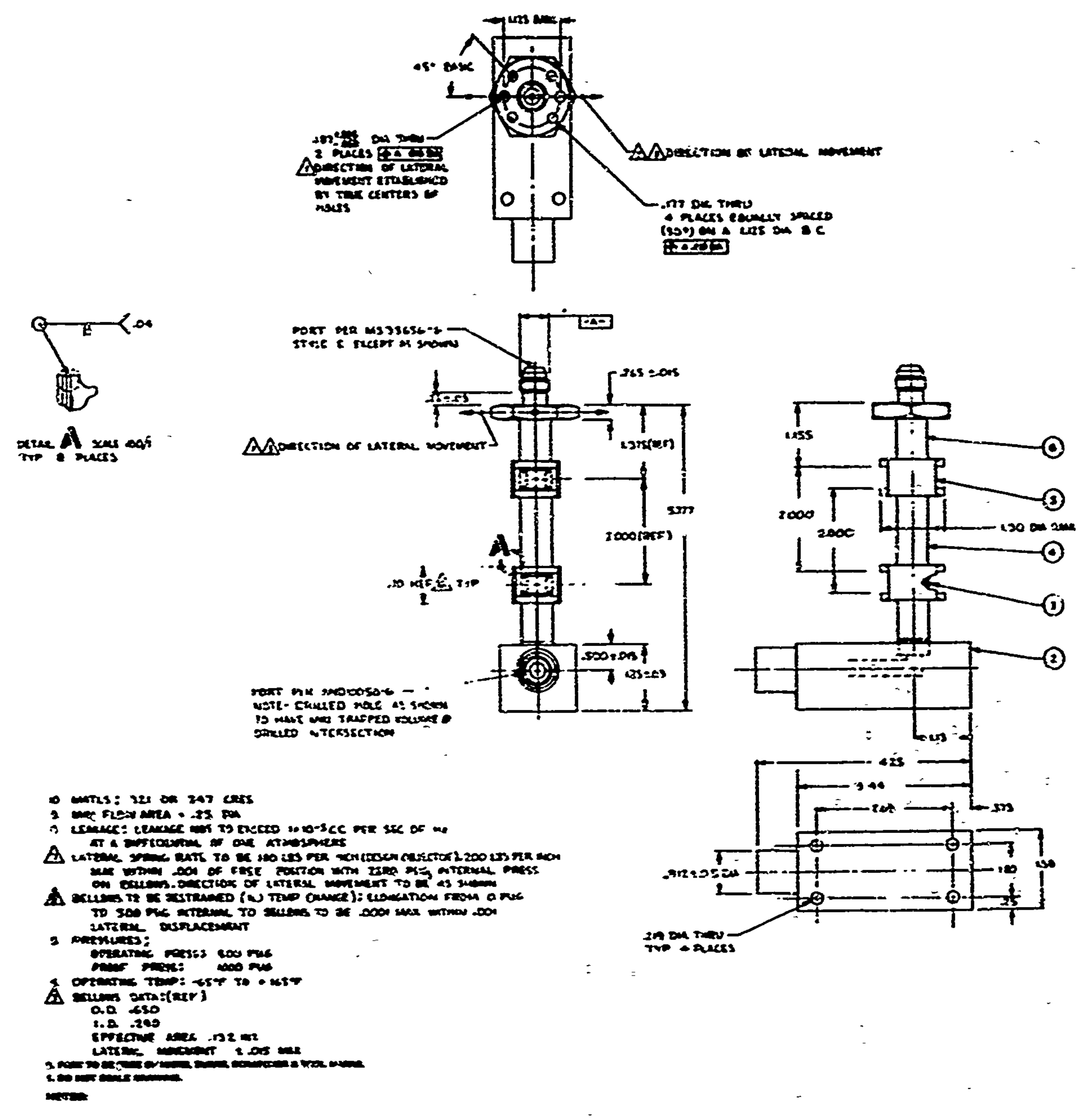


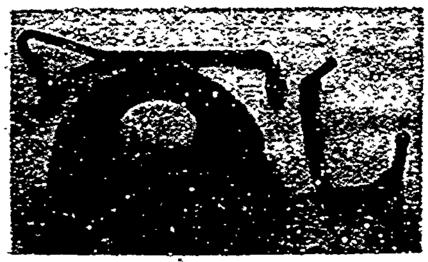
Figure 2. Detail of propellant line bellows fabricated by Metal Bellows Corporation.

All materials used in the bellows units are compatible with N_2O_4 and N_2H_4 fuel blends. The bellows are 3/8 in. with a safety factor of 2 at a working pressure of 500 psi. The porting on the bellows assemblies is AND10050-6. Detail of fabrication are available from Metal Bellows Drawing No. D 57797.

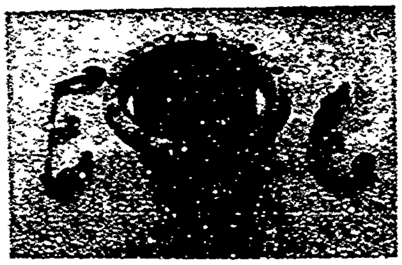
B. ENGINE MOUNTING ADAPTERS

Engine mounting adapters were designed and fabricated which mate the engines (as described in Rocketdyne E207120 and Marquardt E228305 drawings) to the engine mounting platform of the thrust stand system. These adapters are shown in Figure 3. The detailed evaluation of these adapters is included in the discussions of the vibration and force measurements; however, it is generally concluded that no resonance is associated with the adapters below 1000 cps.

The details of fabrication of Engine Mounting Plate A are included in Air Force Drawing No. X65 D 7435; the details of Engine Mounting Plate B are included in Air Force Drawing No. X65 D 7436.



(a) Adapter designed for Marquardt radiation cooled engine.



(b) Adapter designed for Rocketdyne ablative cooled engine.

Figure 3. Engine mounting adapters fabricated for thrust stand system.

SECTION III

SYSTEM TEST

The complete system (including thrust platform, instrumentation console, and hydraulic power supply) was moved to the Environmental Laboratory for this set of measurements. The thrust platform included the items designed under this contract, as well as all items included in Contract AF 04(611)-10536. These measurements established the response characteristics of the thrust stand system.

A. TEST METHOD

1. Sinusoidal Testing

Sinusoidal force input to the stand was provided by coupling an electrodynamic force generator, or "shaker," to the thrust stand. The test setup shown in Figure 4 was used for the first series of tests (sequences No. 1-22). In this series the shaker was coupled to the thrust stand at the engine mounting points through an adapter ring and four Endevco Model 2103-500 force gauges. The test setup is shown schematically in Figure 5. The test setup shown in Figure 6 was used for the second series of tests (sequences No. 23-35). In this series the shaker was coupled to the load cell through a force gauge attached to the calibrator aft end.

The force gauge outputs were used to provide force input level monitoring and control. For the first series of tests, input level control was achieved by amplifying the four force gauge output signals and feeding the amplified signals into a summing network. The output from this summing network represented the vector sum of the individual force inputs to the thrust stand and was applied to the shaker control servo input. During the second series of tests, input level control was achieved as in the first tests, except that only one force gauge was used (eliminating the requirement for the summing amplifier).

Accelerations were measured by piezoelectric accelerometers mounted at the desired locations. All force gauge, accelerometer, and load cell outputs were recorded on oscillograph records and magnetic tape for future analysis. Schematic diagrams showing instrumentation hookups for both series of test are given in Figures 7 and 8.

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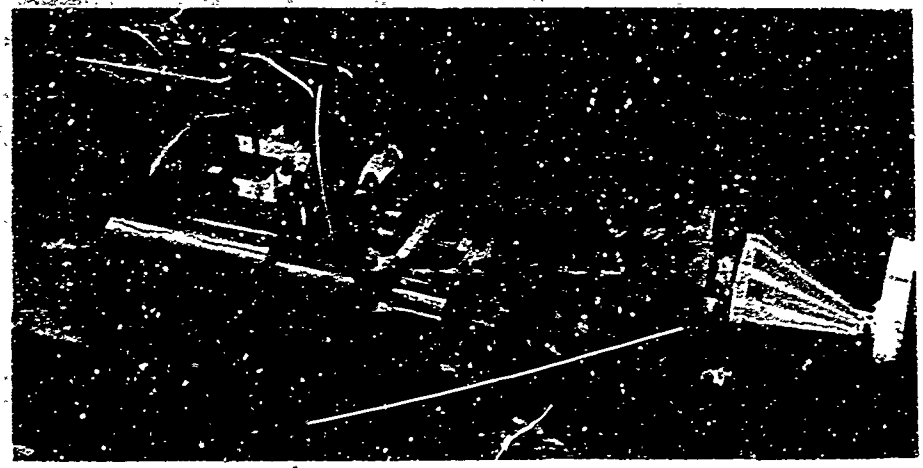

Figure 4. Test setup for first series of tests.

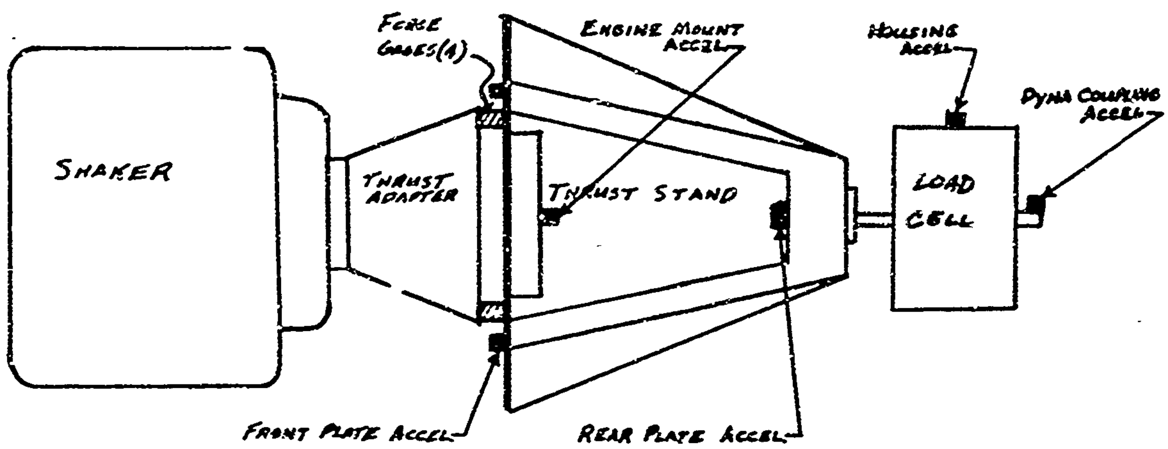

Figure 5. Test setup for applying force to engine attach points.

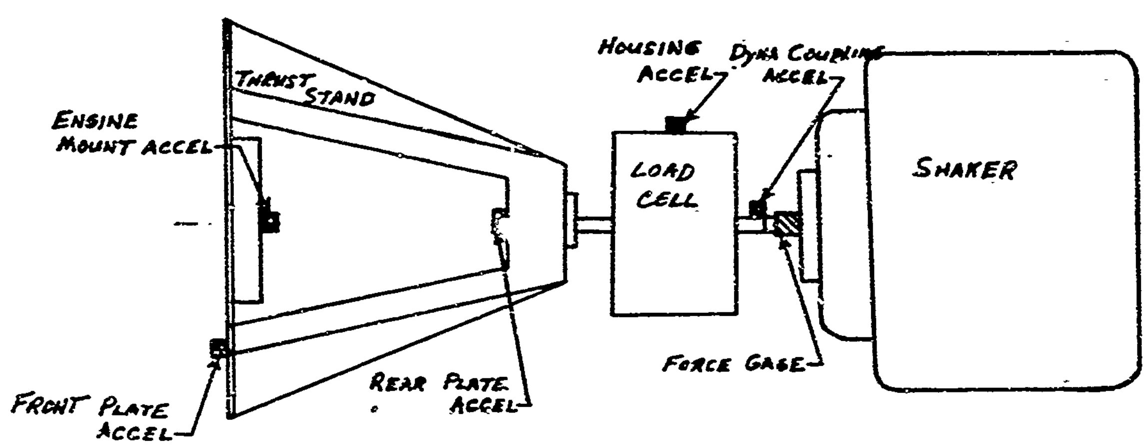

Figure 6. Test setup for applying force input to dynacoupling.

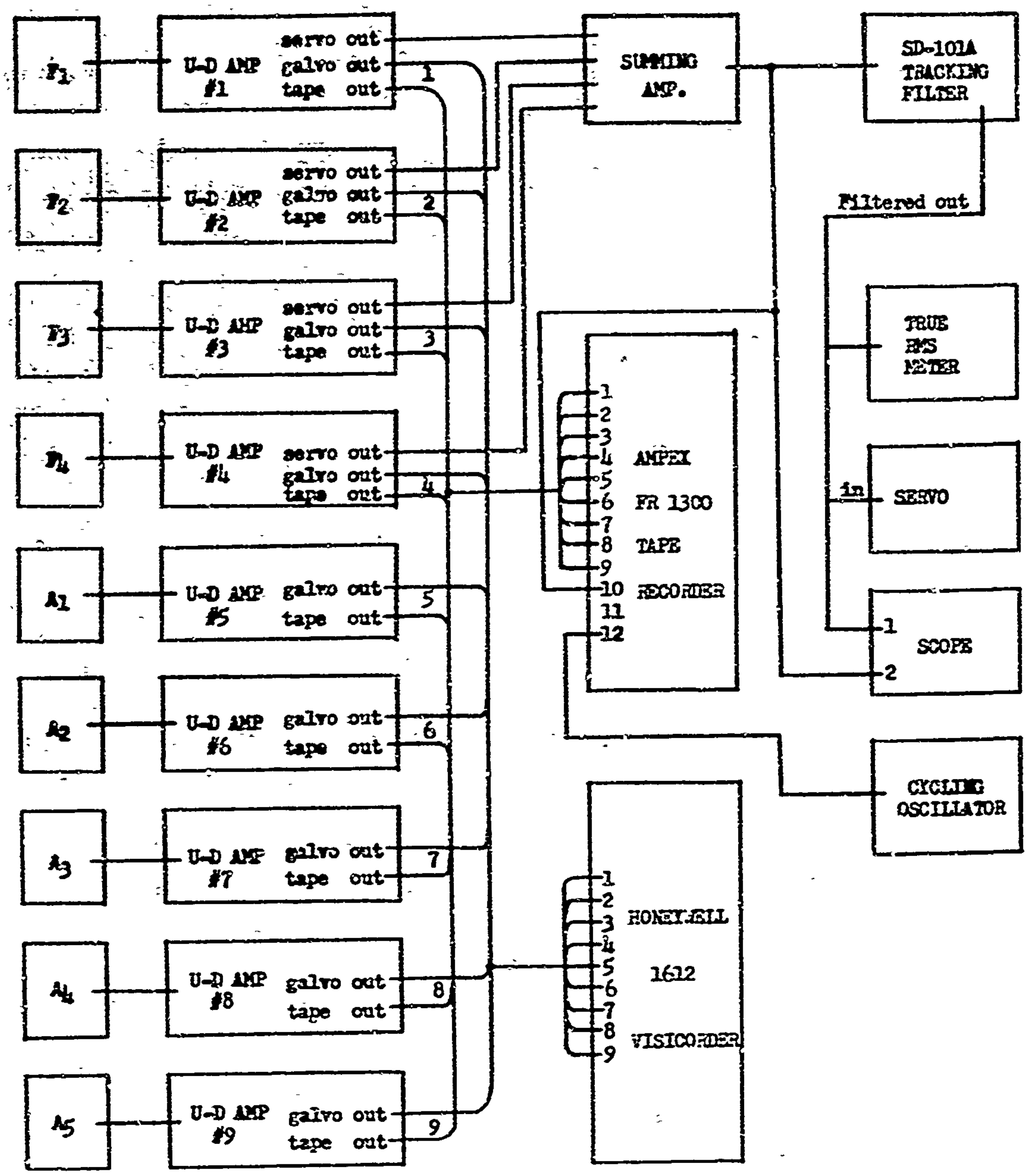

Figure 7. Sinusoidal test instrumentation setup No. 1.

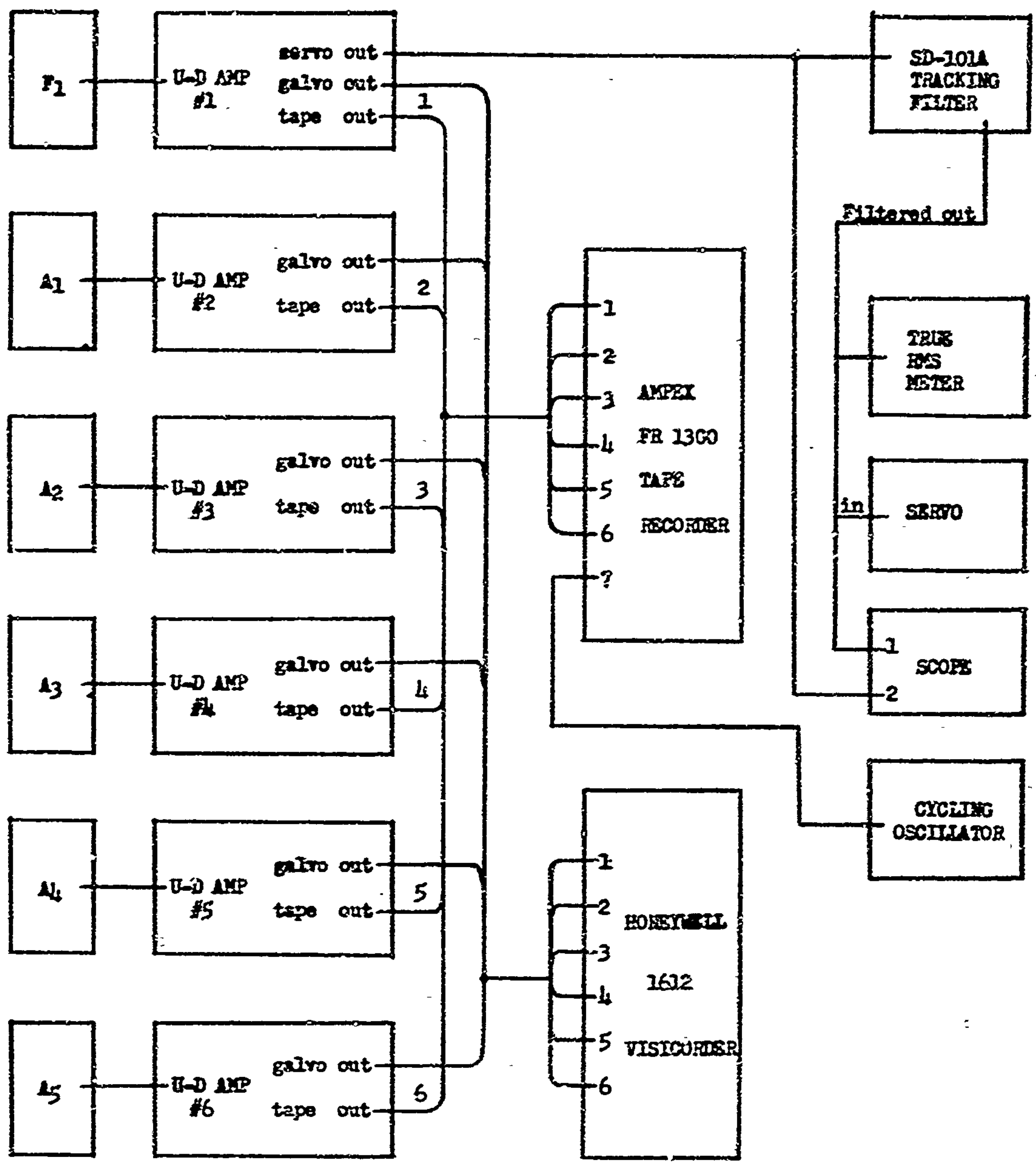

Figure 8. Sinusoidal test instrumentation setup No. 2.

With force input to engine mounting points, tests were run with real and dummy Marquardt and Rocketdyne engines mounted on the thrust stand. During tests where force was to the calibrator, a Marquardt dummy engine was mounted on the thrust stand. Table I lists the test runs.

2. Step Unload Testing

The next type of input, the step unload, is illustrated by the test setup and results shown in Figure 9. The results shown are for a 25 lb run; however, the result does not depend on amplitude in the range up to 100 lb. The results are shown for the complete system and for the system without the platform. The ringing frequency and rise time are about the same; however, the overshoot is greater in the complete system, indicating that the platform contributes to the ringing. The ringing frequency is 570 cps, as indicated on the scope traces. These results are further explained in Section III-A-1 by showing that the differential pressure transducer and the platform are resonant at approximately the same frequency. The input step is shown as measured by a quartz force transducer to illustrate that the rise time of the input is insignificant compared with the rise time of the output pulse.

B. DISCUSSION OF RESULTS

The ratio of force input to the stand to the measured output of the load cell is shown in Figures 10 through 13. Figures 10 and 11 give the force transmissibilities for the dummy and real Marquardt engines, respectively, and Figures 12 and 13 give the force transmissibilities for the dummy and real Rocketdyne engines, respectively. Acceleration transmissibilities are shown in Figures 14 through 17 for the transmissibilities of the engine mount to the front plate for each of the four engines. The ratio of the acceleration of the front of the platform to the force input is shown for sequence No. 22 in Figure 18.

The ability of the load cell to accurately measure the amount of force applied to the engine mount can be evaluated from the force transmissibilities shown in Figures 14 through 17. These figures are practically identical; therefore, the influence of the various engines on the force transmission characteristics of the stand is insignificant. These curves appear fuzzy because the output of the load cell was noisy, and the time constant used in the analysis was insufficient to smooth the curves. As can be seen from these figures the force output remains somewhat less than the input, up to approximately 250 cps.

TABLE I

Test Runs

Sequence No.	Configuration	Level
1	Rocketdyne Dummy Engine	System Calibration
2	" " "	Load Cell Calibration
3	" " "	20 lb Peak
4	" " "	Noise Level
5	" " "	Load Cell Calibration
6	" " "	20 lb Peak
7	" " "	Load Cell Calibration (No Filter)
8	" " "	Repeat of No. 7
9	" " "	Repeat of No. 7
10	" " "	20 lb Peak
11	Rocketdyne Real Engine	20 lb Peak
12	" " "	Repeat of No. 11
13	" " "	System Calibration
14	" " "	Load Cell Calibration
15	" " "	Noise Level
16	" " "	20 lb Peak
17	" " "	Load Cell Calibration
18	" " "	20 lb Peak
19	Marquardt Real Engine	20 lb Peak
20	" " "	20 lb Peak
21	" " "	20 lb Peak
22	Marquardt Dummy Engine	20 lb Peak
23	Input at Calibrator	System Calibration
24	" " "	Repeat of No. 23
25	" " "	Load Cell Calibration
26	" " "	Noise Level
27	" " "	20 lb Peak
28	" " "	Load Cell Calibration
29	" " "	System Calibration
30	" " "	20 lb Peak
31	" " "	Load Cell Calibration
32	" " "	Repeat of No. 31
33	" " "	100 lb Peak
34	" " "	Noise Level
35	Input at Calibrator (Platform Decoupled)	100 lb Peak

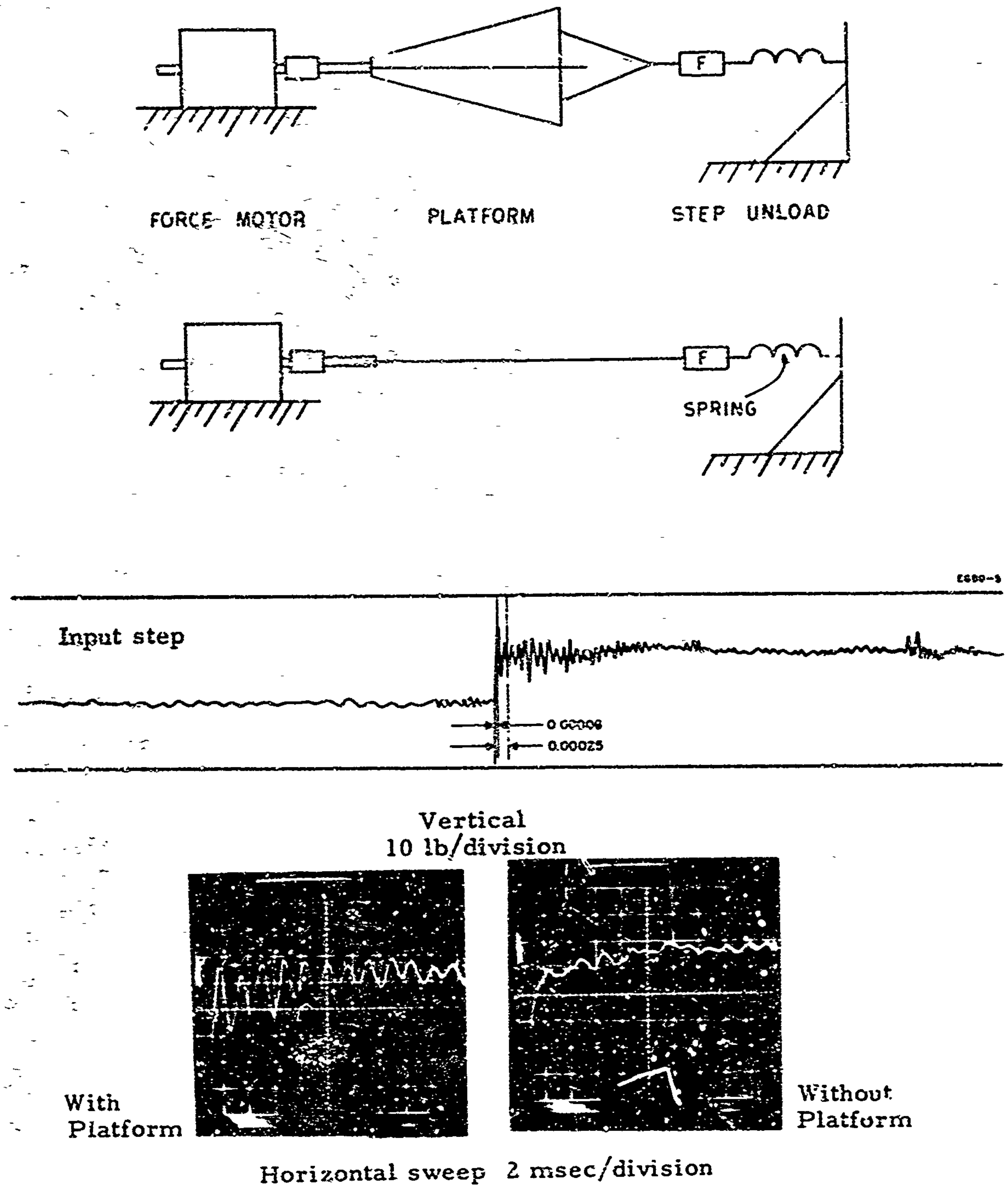

Figure 9. Step unload test setup and results.

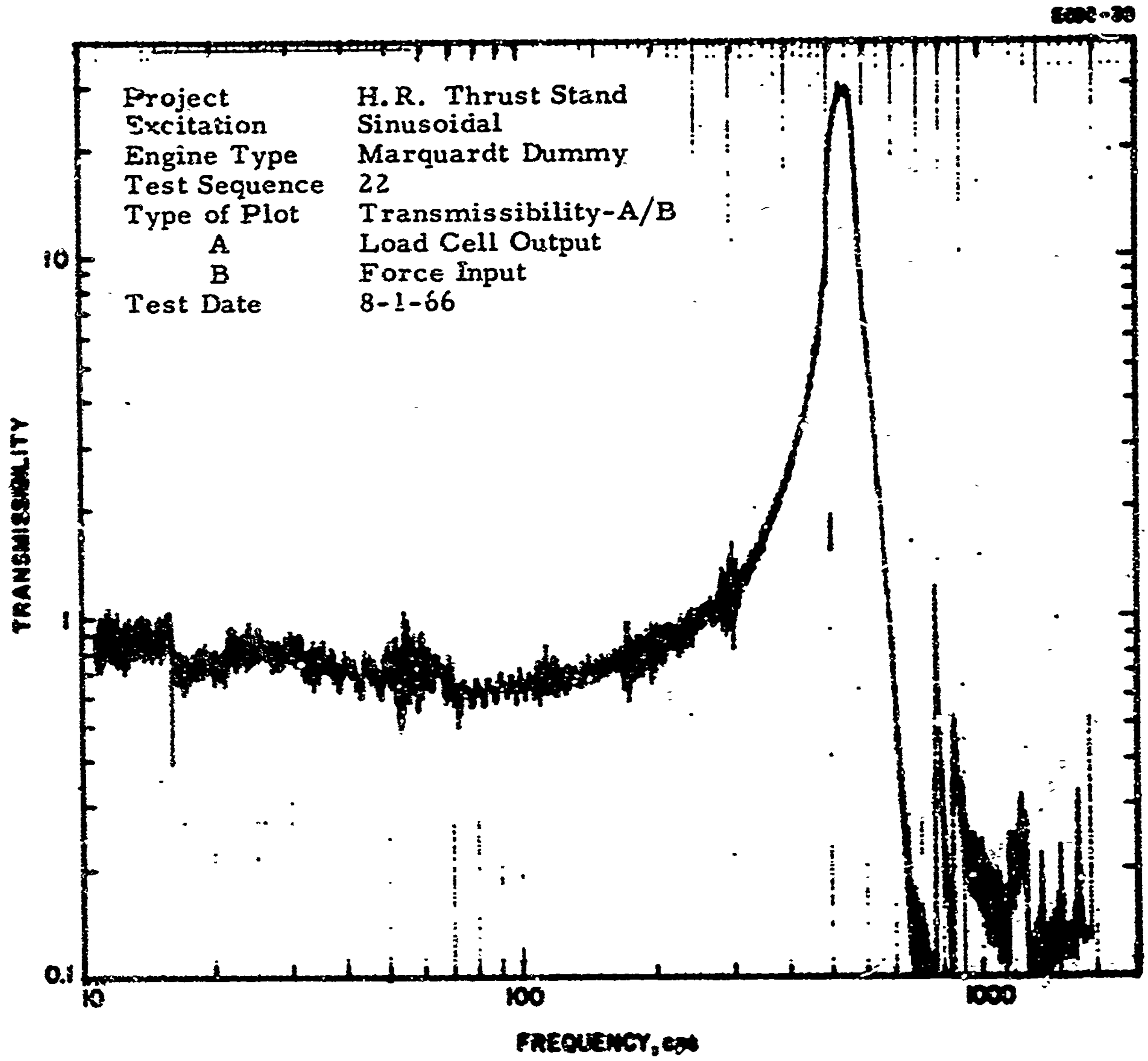

Figure 10. Force transmissibility for dummy Marquardt engine.

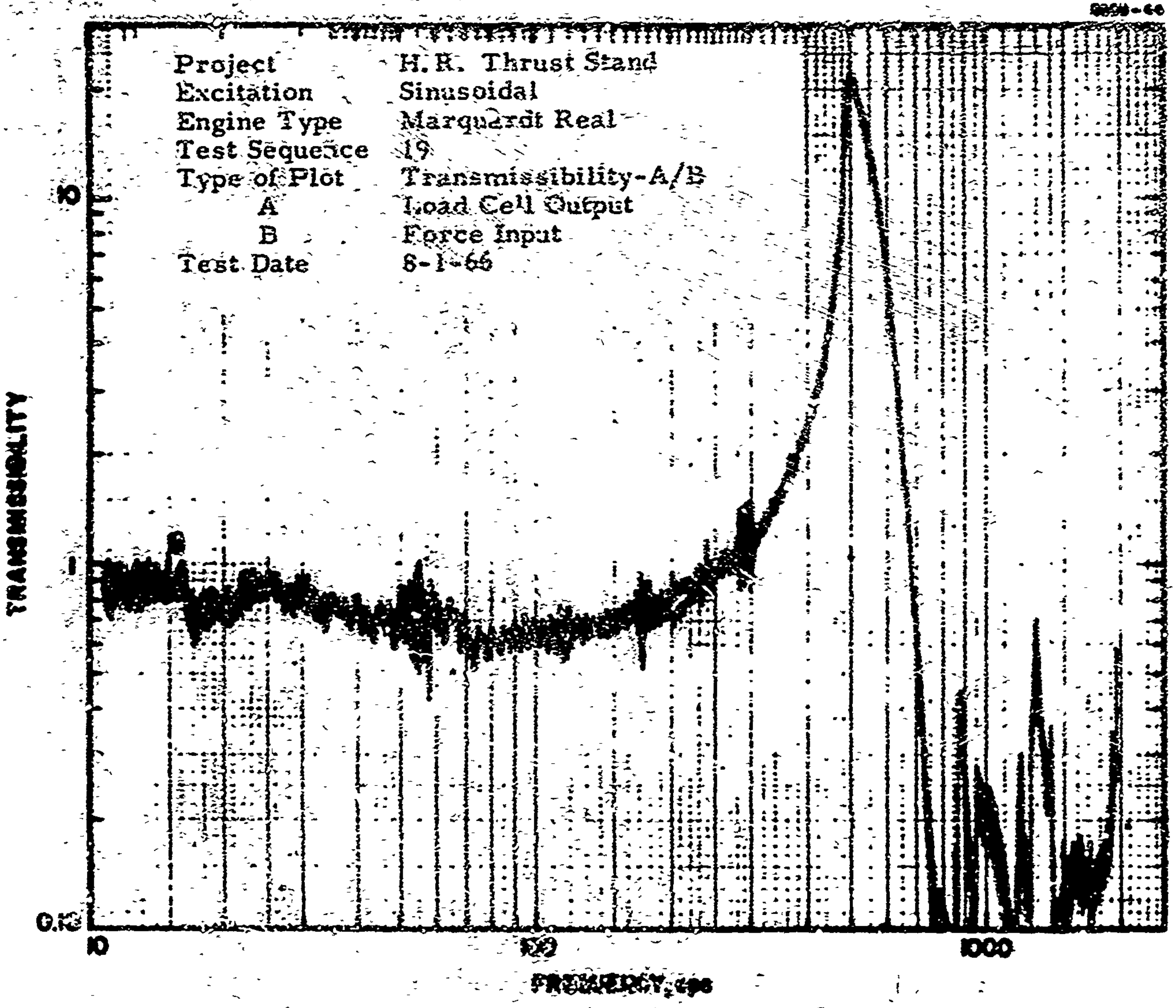

Figure 11. Force transmissibility for real Marquardt engine.

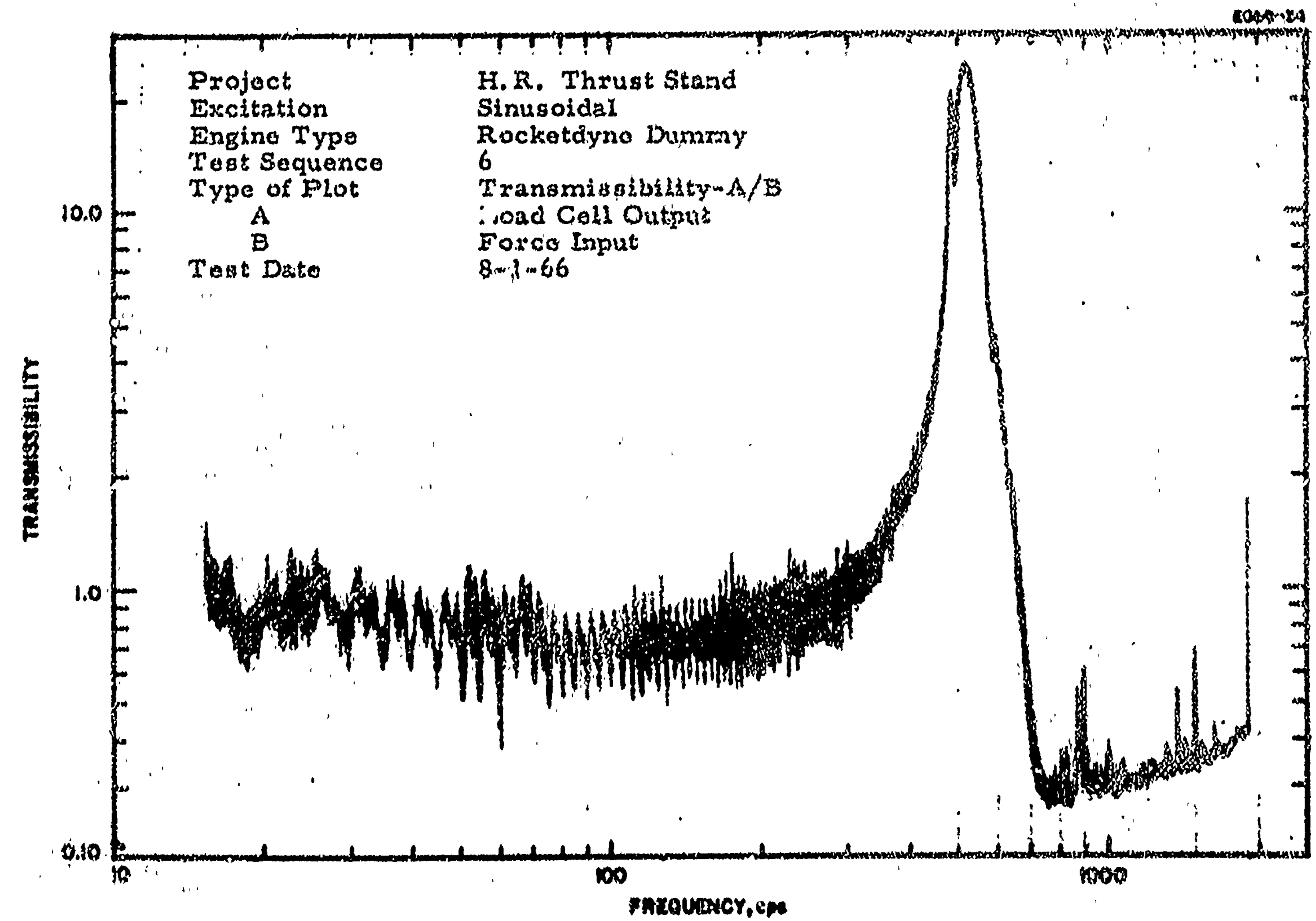

Figure 12. Force transmissibility for dummy Rocketdyne engine.

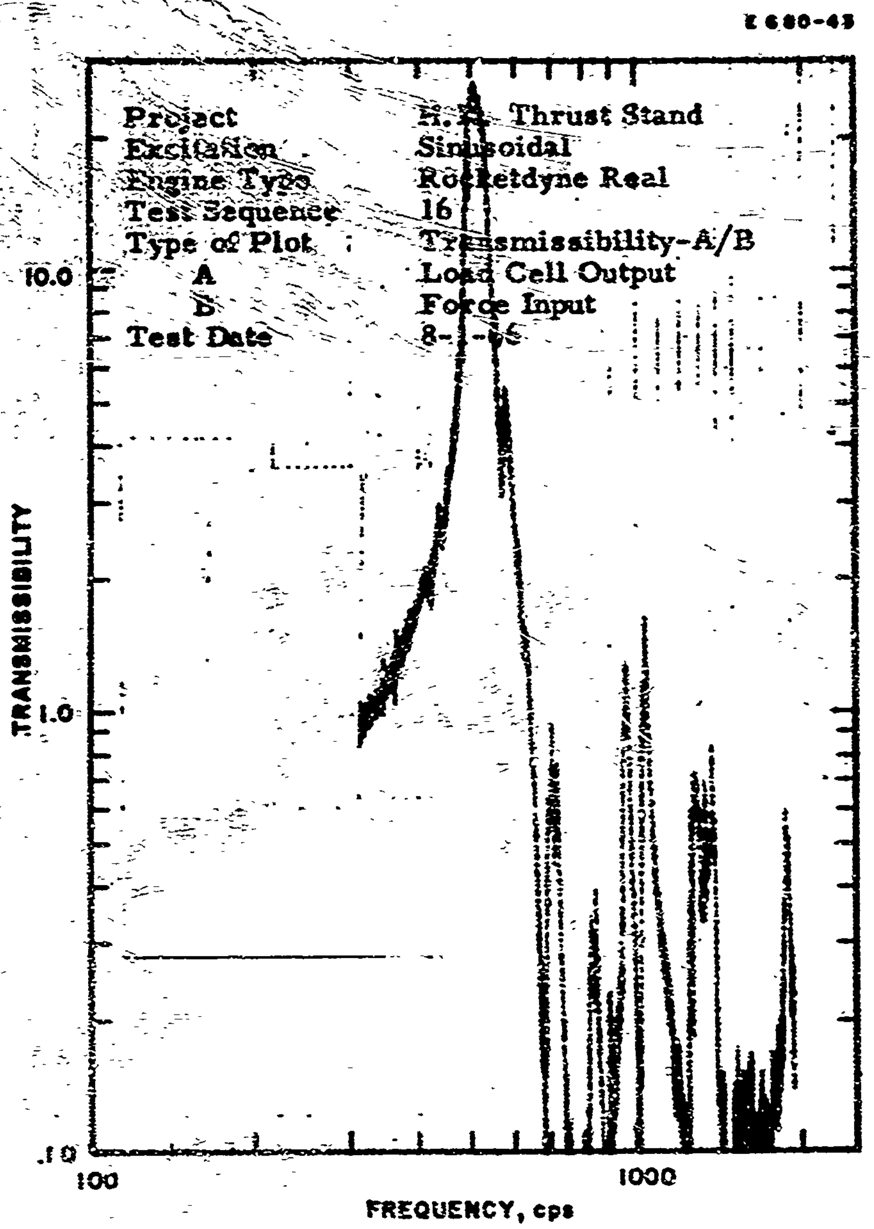

Figure 13. Force transmissibility for real Rocketdyne engine.

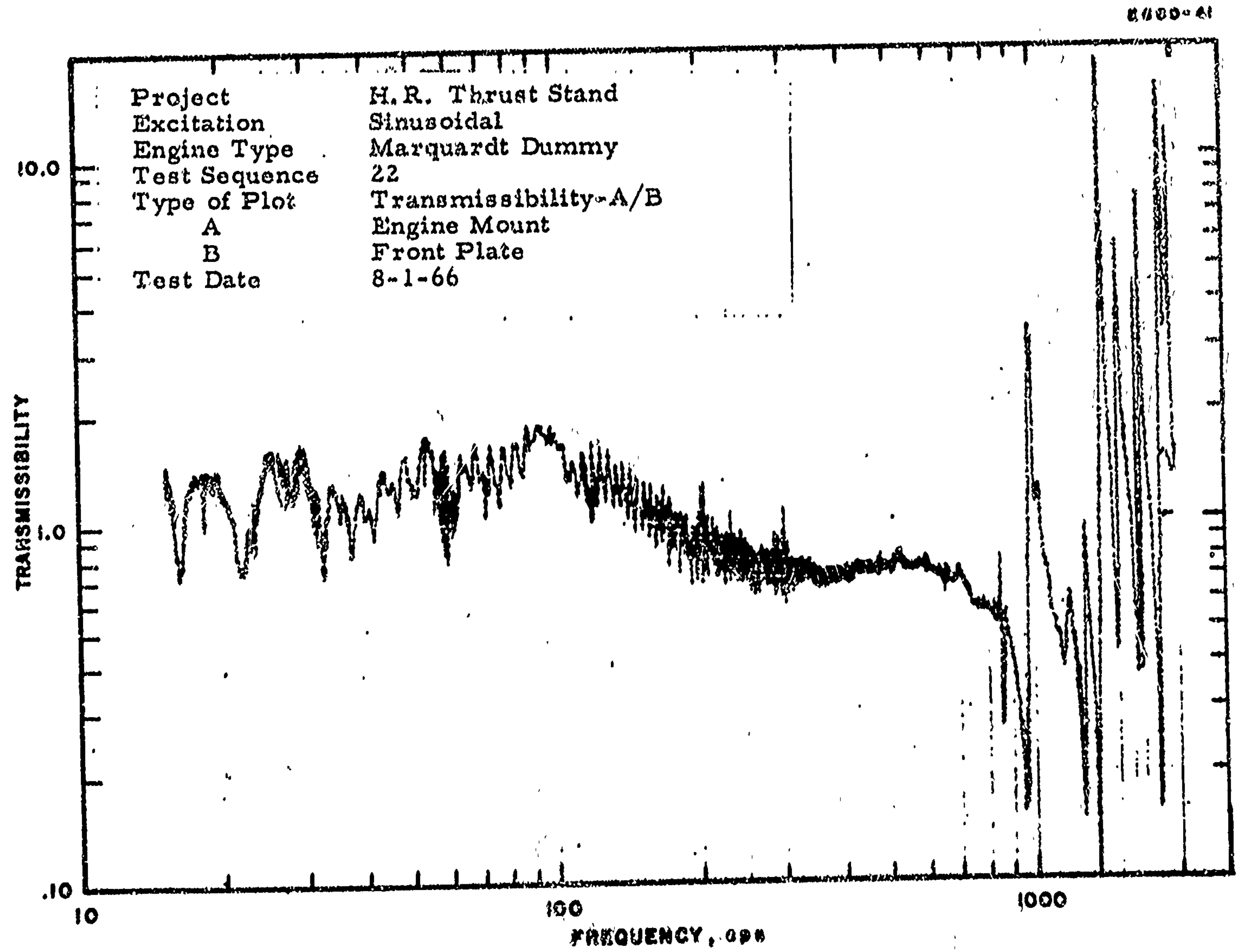

Figure 14. Acceleration transmissibility for dummy Marquardt engine.

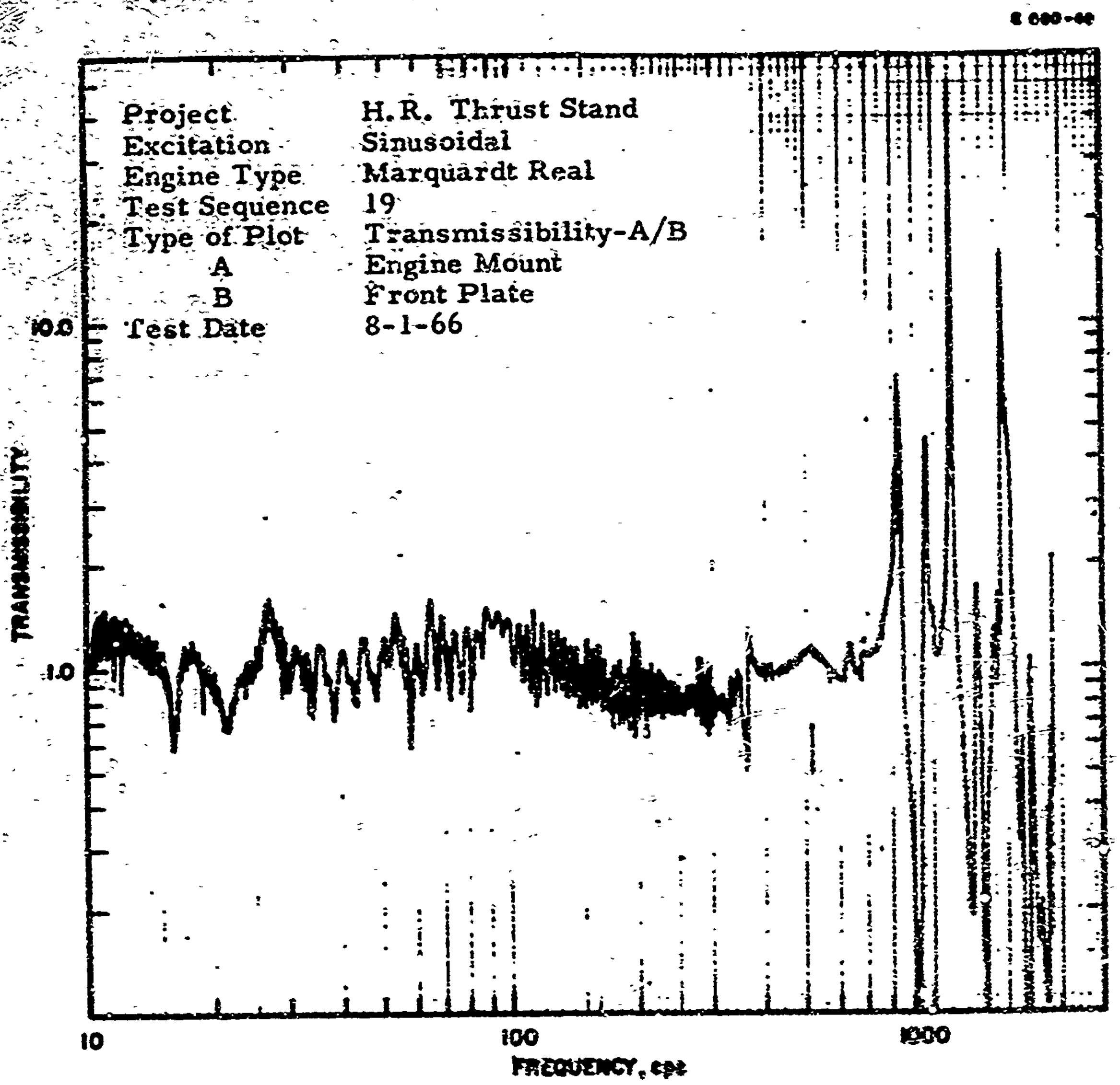

Figure 15. Acceleration transmissibility for real Marquardt engine.

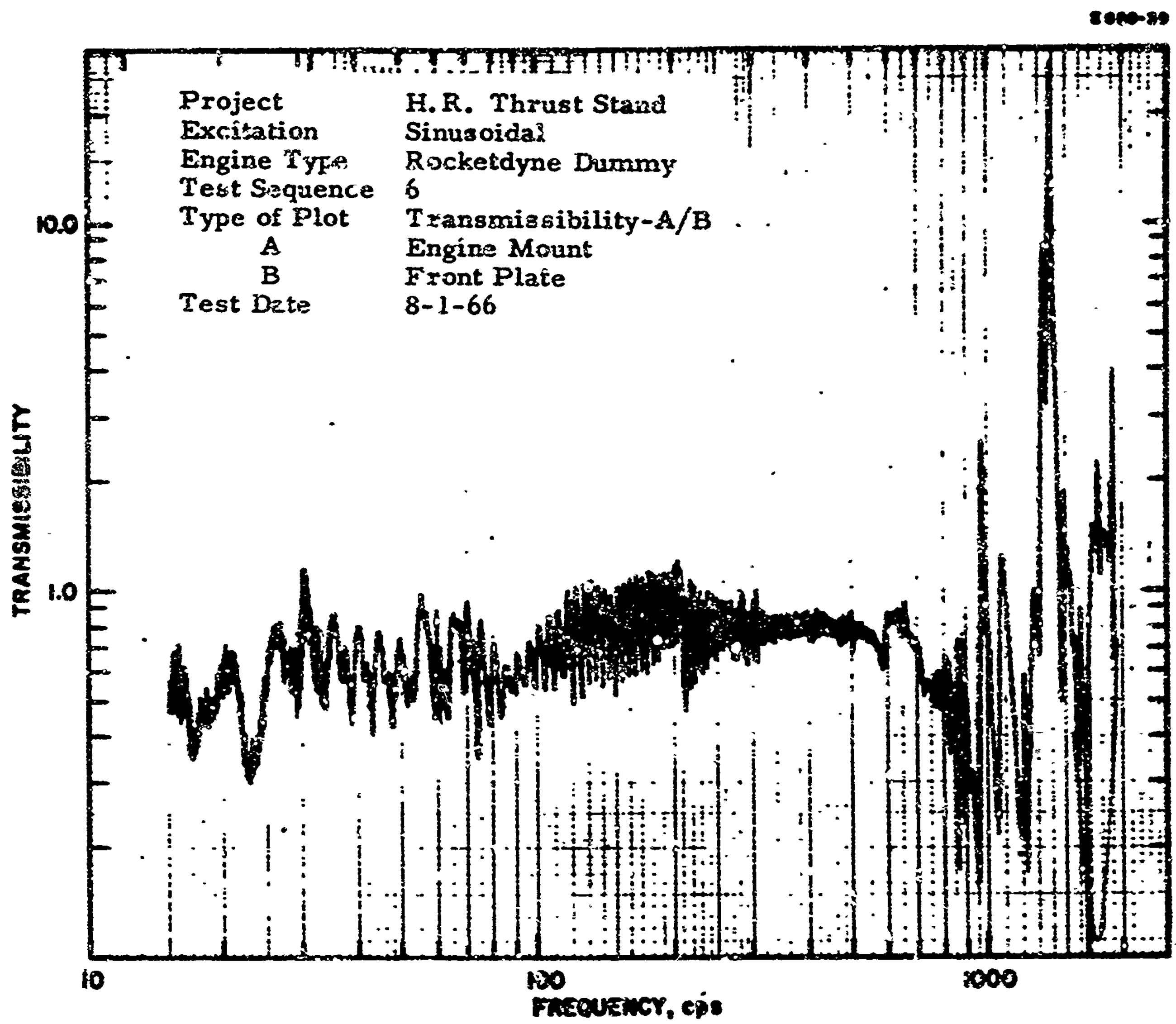

Figure 16. Acceleration transmissibility for dummy Rocketdyne engine.

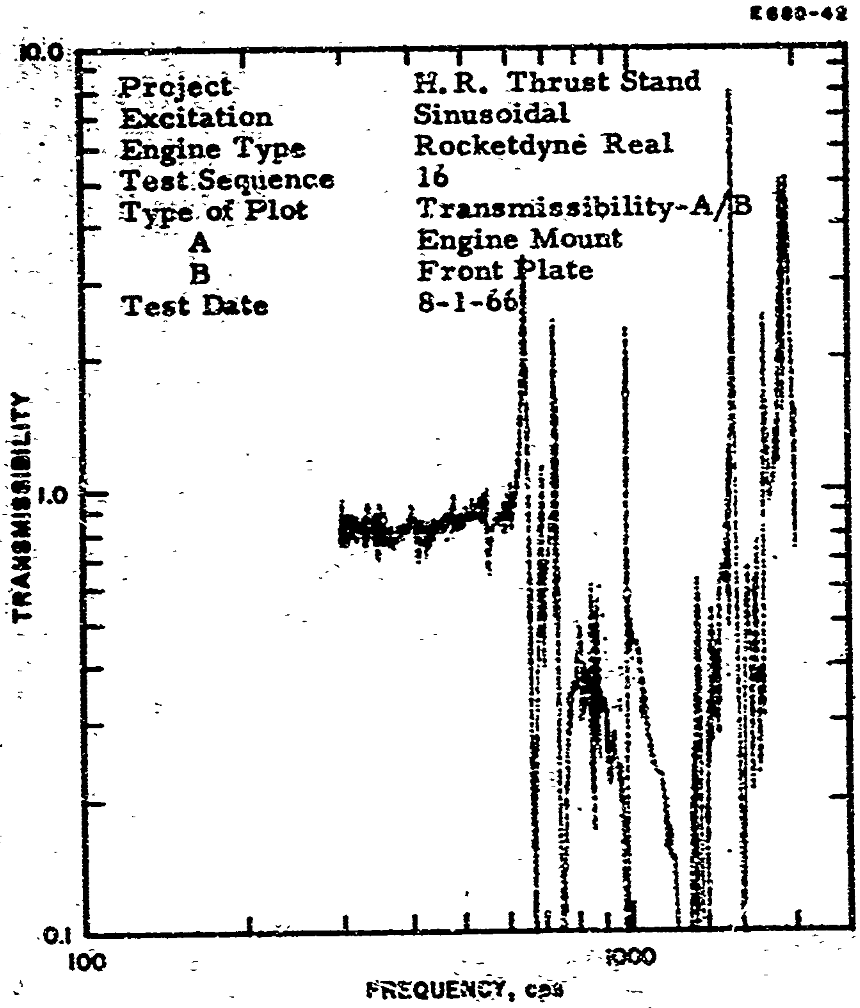

Figure 17. Acceleration transmissibility for real Rocketdyne engine.

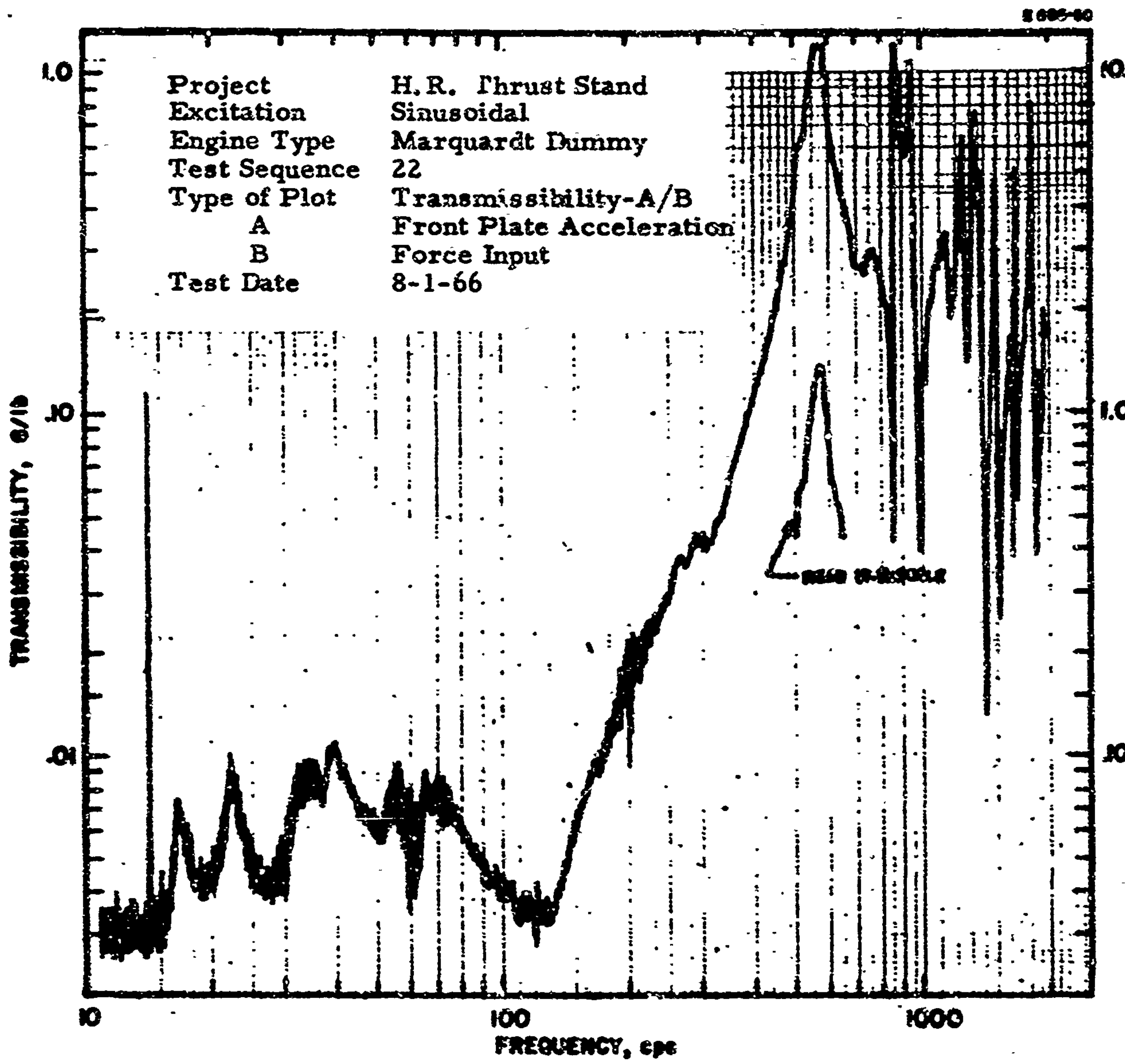

Figure 18. Ratio of acceleration to force input.

Above 250 cps the output is amplified; it peaks at 550 cps, reaching a value approximately 25 times the input. Beyond 550 cps the output drops off rapidly and becomes undefinable because of the influence of structural resonances in the stand. After these tests it was determined that the clearance of the load cell spool in the housing was too small and friction forces were appreciable. The spool has since been machined to reduce this friction force; the friction may well have accounted for the transmissibilities being less than 1.0 below 250 cps. The system spring constant was calculated to be approximately one-half million pounds per inch; because of this high spring constant and corresponding low force input the deflection and resulting accelerations were very low at frequencies below the system resonance. Figure 19 is a plot of the theoretical acceleration of the platform for a force input of 20 lb based on a single-degree-of-freedom system with a resonant frequency of 550 cps and an amplification factor of 25. This figure illustrates the wide range of accelerations which occur from 20 to 2000 cps. With the instrumentation calibrated so that the maximum acceleration was full scale, the noise floor of the instrumentation was between 0.3 and 0.1 G. This region is shown in Figure 18, and illustrates the difficulty in measuring the acceleration below 300 cps.

Therefore, because of low voltage signals, the validity of the acceleration transmissibilities (Figures 14 through 17) is questionable below 300 cps. Above 300 cps these figures can be considered accurate; they show no resonance in the engine mount between 300 and 550 cps.

The lumped mass system shown in Figure 20 was developed to illustrate the first mode shape and relative stiffnesses of the system. The weight distribution used for this model is only an approximation, since the purpose of the model is to indicate only the relative mode shape. The stiffness values used in the model were estimated from a knowledge of the system's natural frequency (550 cps) and the relationship of the over-all stiffness to the force motor stiffness. This relationship between load cell stiffness and system stiffness was determined from Figure 21. This figure, which gives the acceleration transmissibility of the front of the platform to the rear of the platform and is accurate above 300 cps, indicates that the motion at the front of the platform is approximately ten times that at the rear. Therefore, the system spring constant measured at the front of the platform is approximately one-tenth that at the aft end. The acceleration of the first mass of this model (Figure 20) divided by the force input (based on a system Q of 25) is shown in Figure 22. This figure can be compared with Figure 18, which is the ratio of the measured acceleration at the front of the platform to the force input. The fact that Figure 18 is comparable to Figure 22 indicates that the lumped-mass model of the system is valid.

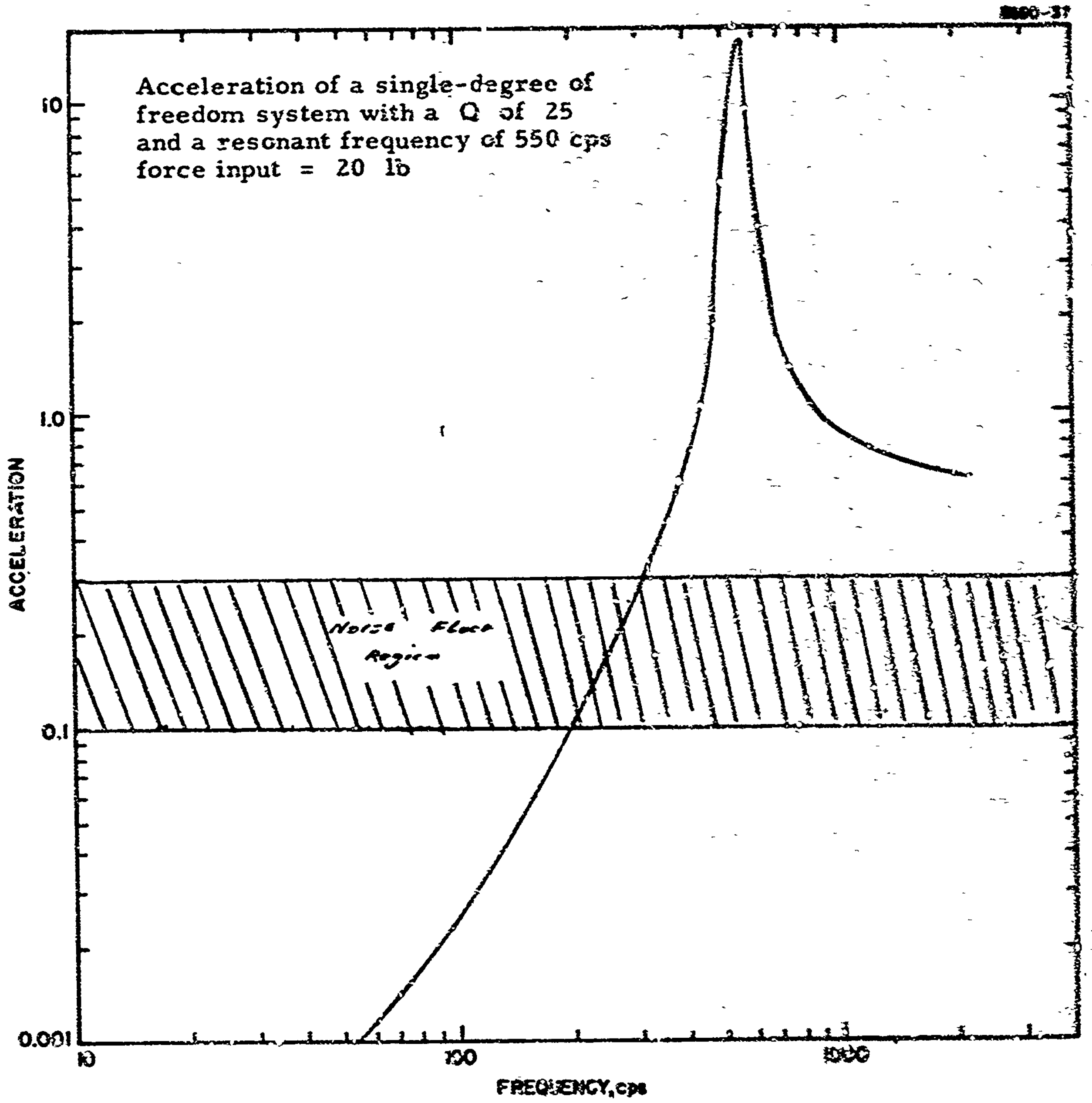

Figure 19. Theoretical acceleration.

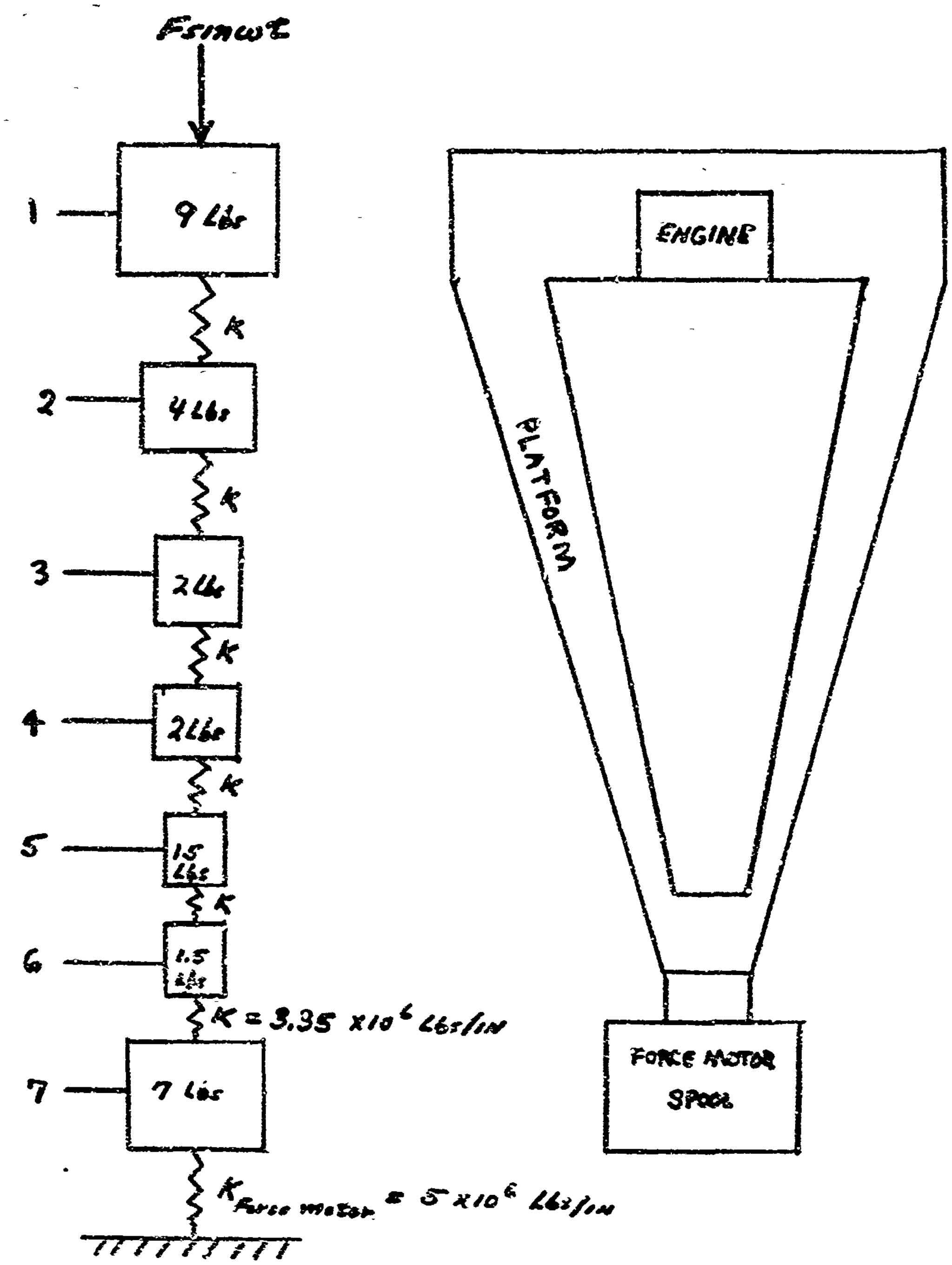

Figure 20. Lumped-mass model of thrust stand system.

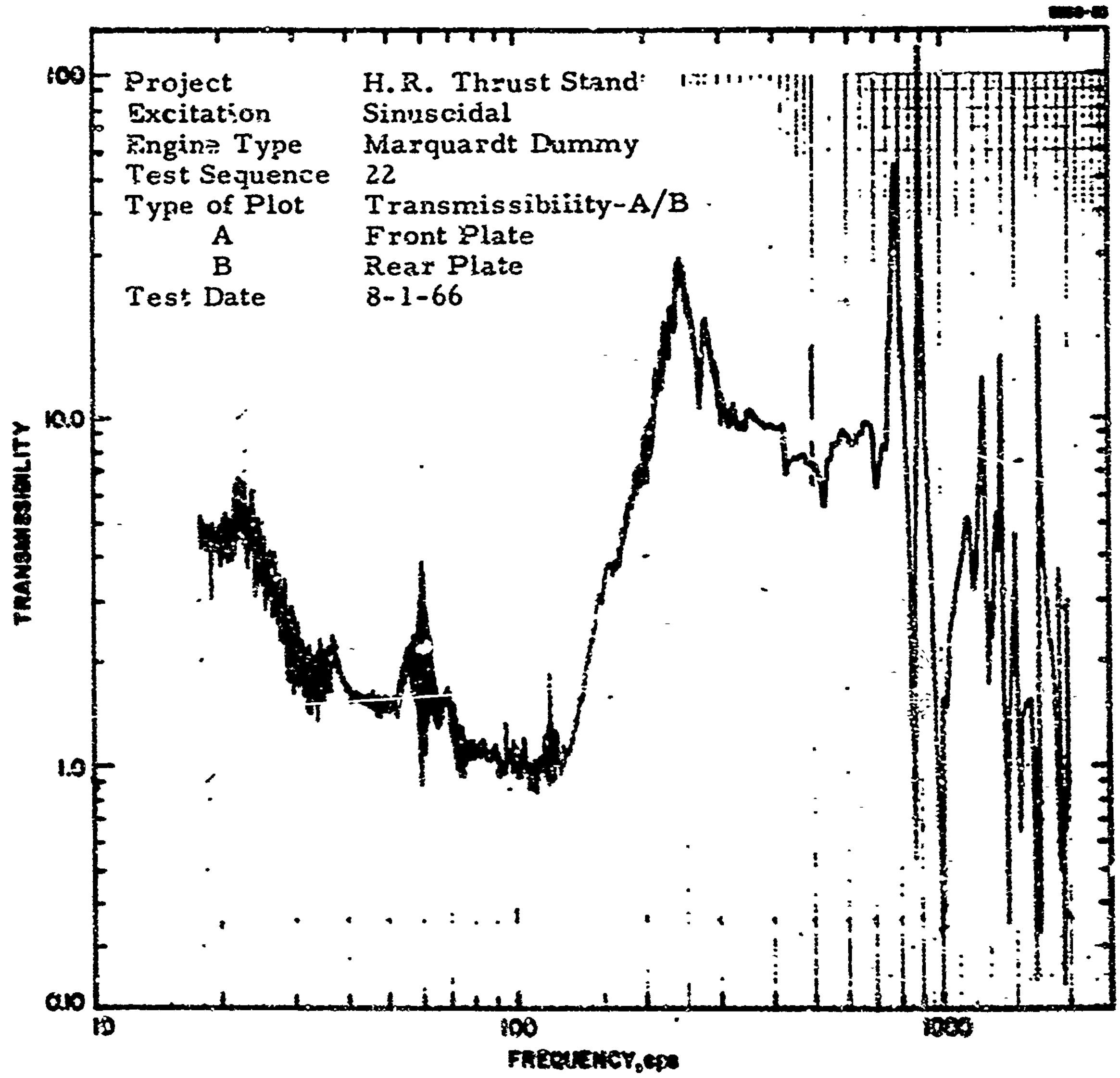

Figure 21. Acceleration transmissibility.

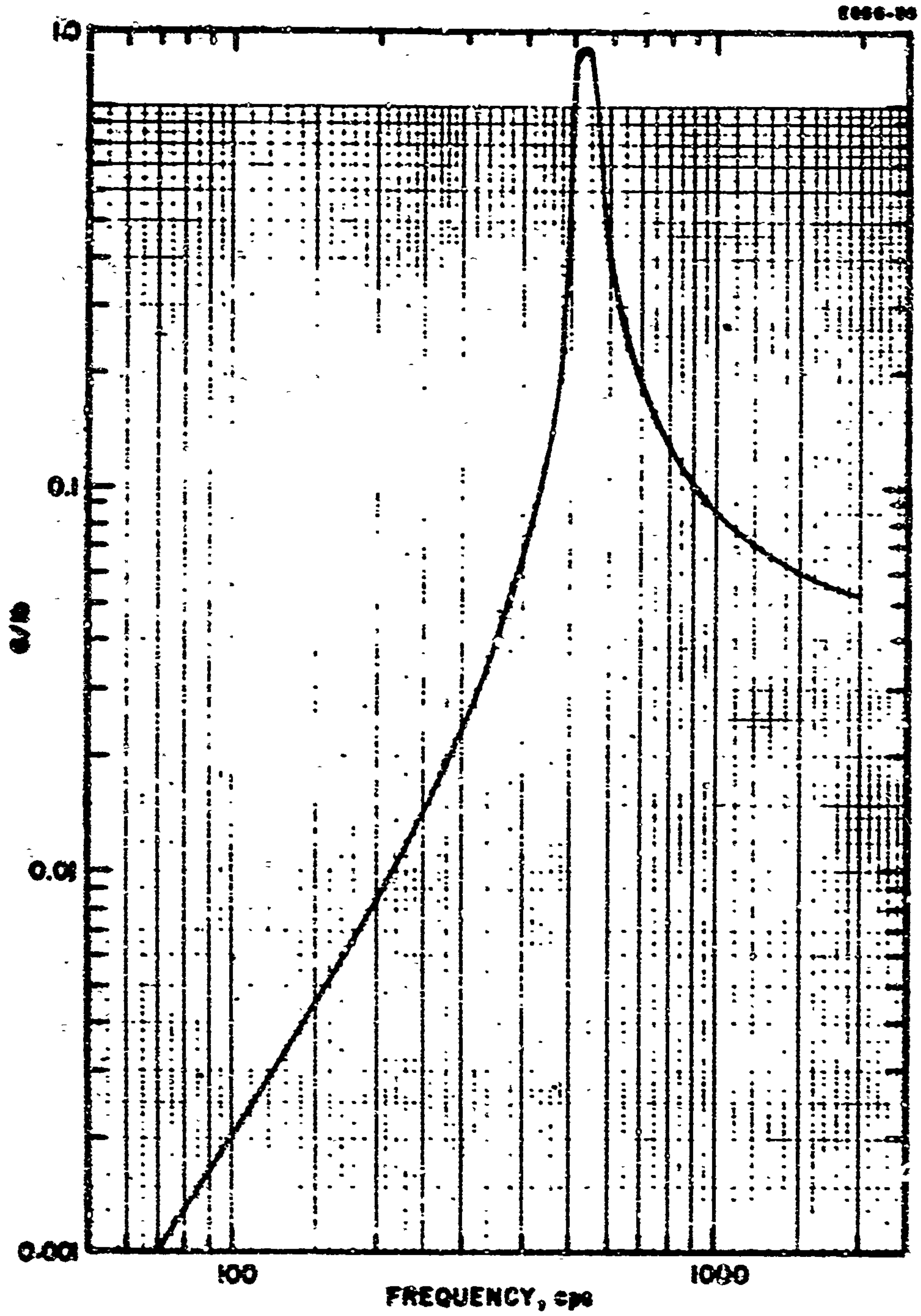

Figure 22. Theoretical acceleration-force ratio.

When the system is driven from the calibrator end, the force output was less than one-tenth of the input. Misalignment of the shaker and thrust stand axis could have created a friction force which would lead to this result. With a force input of 100 lb the output was less than 10 lb and in the noise floor of the accelerometers. The resonances of the system as identified by this second series of test were the same as those in the first series. The load cell was driven without the engine mounting platform, and no resonances were found to be present. This test covered the frequency range from 10 to 2000 cps. The output from the load cell as read on the pressure transducer increased to about double amplitude at 600 cps and then dropped off quickly as the frequency increased.

C. CONCLUSIONS

The important conclusions which can be reached as a result of these tests are

1. With an engine mounted in the platform the first resonant frequency of the stand is 550 cps with a peak amplification factor of 25.

2. The 550 cps is a structural resonance of the platform-load cell system, including the differential pressure transducer. The amplification of the pressure transducer at 550 cps is approximately 2.

3. The system spring constant is approximately 5×10^5 lb/in. and the load cell spring constant is approximately 5×10^6 lb/in.

4. The engines tested in this program have no significant effect on the force transmission characteristics of the thrust stand system.

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13. ABSTRACT

This report presents the results of a dynamic evaluation of a Thrust Stand System designed under Contract AF 04(611)-10536. The testing includes sinusoidal power measurements from 10 cps to 2000 cps using an electrodynamic shaker as the input force and step unload force input with a decay time of less than 0.1 msec. The results are presented in terms of acceleration, displacement, and force as appropriate to the components under test.

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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.